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LOW NO_x/SO_x BURNER TRIALS: CFB GAGETOWN

G.K. Lee and R.J. Philp
Combustion and Carbonization Research Laboratory

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by

G.K. Lee* and R.J. Philp**

ABSTRACT

The effectiveness of a staged burner concept with limestone injection to control nitrogen (NO_x) and sulphur oxides (SO_2 and SO_3) emissions from a pulverized coal fired generator at Canadian Forces Base Gagetown has been successfully demonstrated. The retrofit installation was capable of achieving up to 50% reduction in NO_x and SO_2 emissions from the combustion of Eastern Canadian coals containing 3% sulphur and 10% ash, with an improvement in generator efficiency.

The limestone injection multi-staged burner (LIMB) installation was safely and reliably operated during the 1987/88 heating season following a number of design modifications to the coal burner and limestone metering systems. Its overall performance will be monitored during the next two heating seasons to evaluate its long-term availability.

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* Manager, ** Research Engineer, Combustion and Carbonization Research Laboratory, Energy Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa, K1A 0G1

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ESSAIS D'UNE CHAMBRE DE COMBUSTION A EMISSIONS DE NO_x/SO_x

par

G.K. Lee* and R.J. Philp**

RESUME

L'efficacité d'une combustion par étapes avec injection de calcaire pour réduire l'émission d'oxydes d'azote (NO_x) et de soufre (SO_2 et SO_3) par un générateur alimenté au charbon en poudre à la base des Forces canadiennes de Gagetown a été démontrée avec succès. L'installation modifiée produit 50% moins de NO_x et de SO_2 à partir de charbons de l'Est canadien contenant 3% de soufre et 10% de cendres, avec un rendement du générateur amélioré.

L'installation de combustion par étapes avec injection de calcaire, appelée LIMB, a fonctionné de façon sûre et fiable pendant la periode de chauffage 1987-1988 après que certaines modifications ont été apportées au brûleur à charbon et au système de comptage du calcaire. Son rendement global sera contrôlé au cours des deux prochaines périodes de chauffage dans le but d'en évaluer la disponsibilité à long terme.

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* Gestionnaire, **ingénieur, Laboratoire de recherche sur la combustion et la carbonisation, Laboratoires de recherche sur l'énergie, CANMET, Energie, Mines et Ressources Canada, Ottawa, K1A 0G1

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INTRODUCTION

In early 1982, the Canada Centre for Mineral and Energy Technology (CANMET) of the Department of Energy, Mines and Resources together with the Directorate for Base Maintenance of the Department of National Defence initiated a joint project to install a novel pulverized-coal combustion system on Generator No. 2 at the Central Heating Plant at Canadian Forces Base Gagetown. The objective of this retrofit installation was to demonstrate the effectiveness of using a multi-staged burner system with sorbent injection for reducing acid gas emissions during the combustion of Eastern Canadian coal. The plant supplies medium temperature hot water to a district heating system and normally burns a high-volatile bituminous coal containing 3% sulphur and 10% ash.

The contract for the heating plant and boiler modifications was funded by CANMET and administered by Defence Construction Canada. On completion of the construction phase, the Combustion and Carbonization Research Laboratory (CCRL) of CANMET's Energy Research Laboratories evaluated the equipment performance and modified a number of system components to improve operational availability.

The temperature field, flame pattern and combustion efficiency for the staged burners at full load were also predicted by three-dimensional modelling. All of the technology changes and the subsequent equipment acceptance trials were carried out by the staff of the Central Heating Plant under the direction of CCRL. Stack emissions during the field trials were measured by the Pollution Measurement Division of Environment Canada.

This report describes Generator No. 2 and its ancillaries, the retrofitted burner and sorbent injection system, the equipment modifications, the modelling study, and the results of the baseline, commissioning, modified burner, burner development and acceptance tests.

The data generated during the acceptance tests are part of Canada's contribution to a cost-shared International Energy Agency Agreement on low NO_x Coal Combustion. Under this agreement the results of parallel demonstration trials in Canada, Denmark and Sweden are being evaluated using a common methodology and a proprietary report will be made available to participants in each country.

GENERATOR DESCRIPTION

Generator No. 2, which is rated at 17 MWt and shown schematically in Figures 1 and 2, has two burners, each supplied by a dedicated pulverizer. This feature, together with an ash disposal system capable of removing the ash overload due to limestone injection, made the plant an ideal site for demonstrating staged combustion of coal.

Normally, only the lower burner is used for generator loads below 60%; both burners are operated at higher loads. Although capable of operating without oil support, the burners are co-fired continuously with about 3% oil to prevent ignition failure caused by sudden interruptions in pulverizer output when the incoming coal is wet or frozen.

Coal, sized at 32 mm x 0, is fed from an overhead bunker via a rotary feeder to a ball-race pulverizer set to provide a minimum fineness of 75 wt % less than 74 x 10^{-6} m. The pulverizer is normally supplied with primary air up to 200°C, but can be supplied with higher temperature flue gas, withdrawn from the furnace hopper, to provide enhanced coal drying. Typically, pulverizer outlet temperatures are 80°C to 95°C while secondary air temperatures to the burner are 180°C to 250°C.

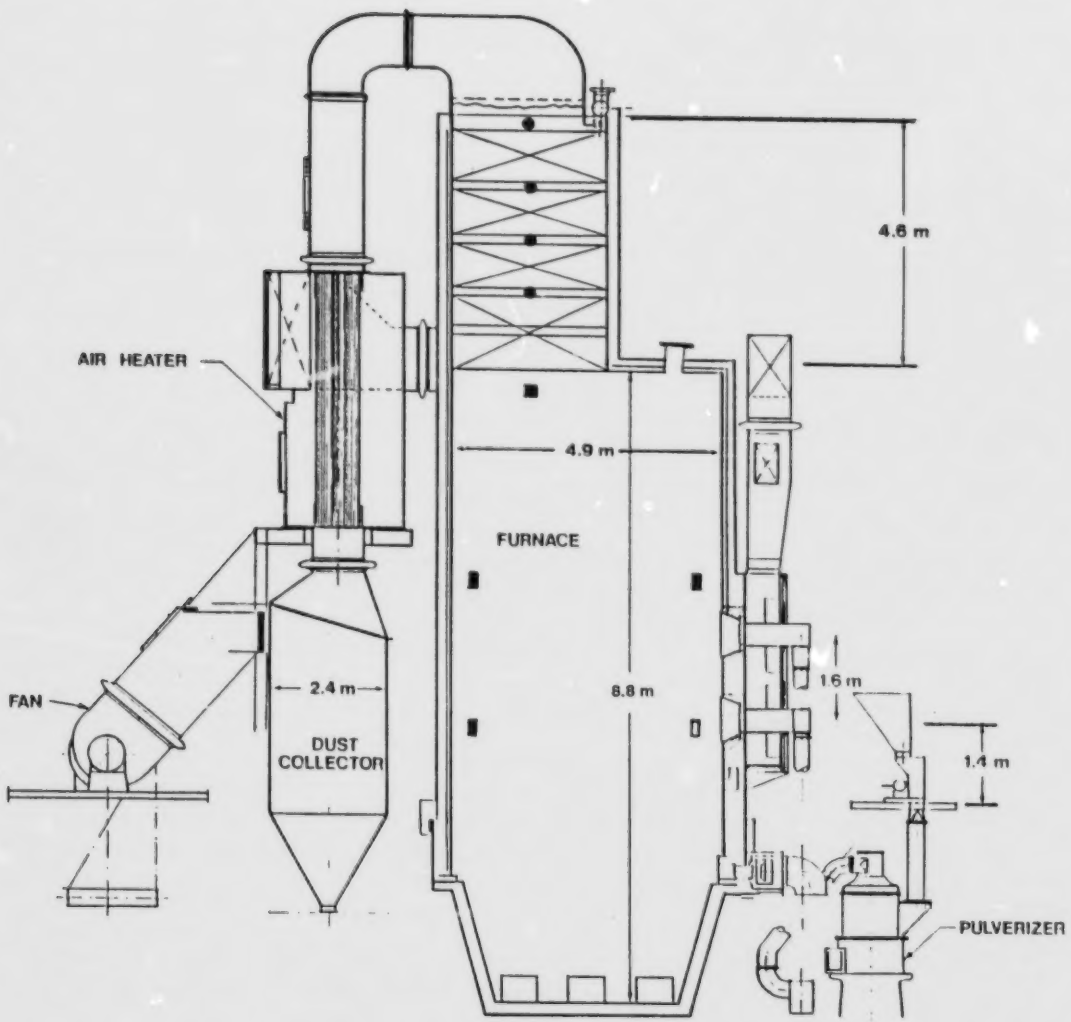


Fig. 1 - Side View: No.2 Generator – Gagetown CHP

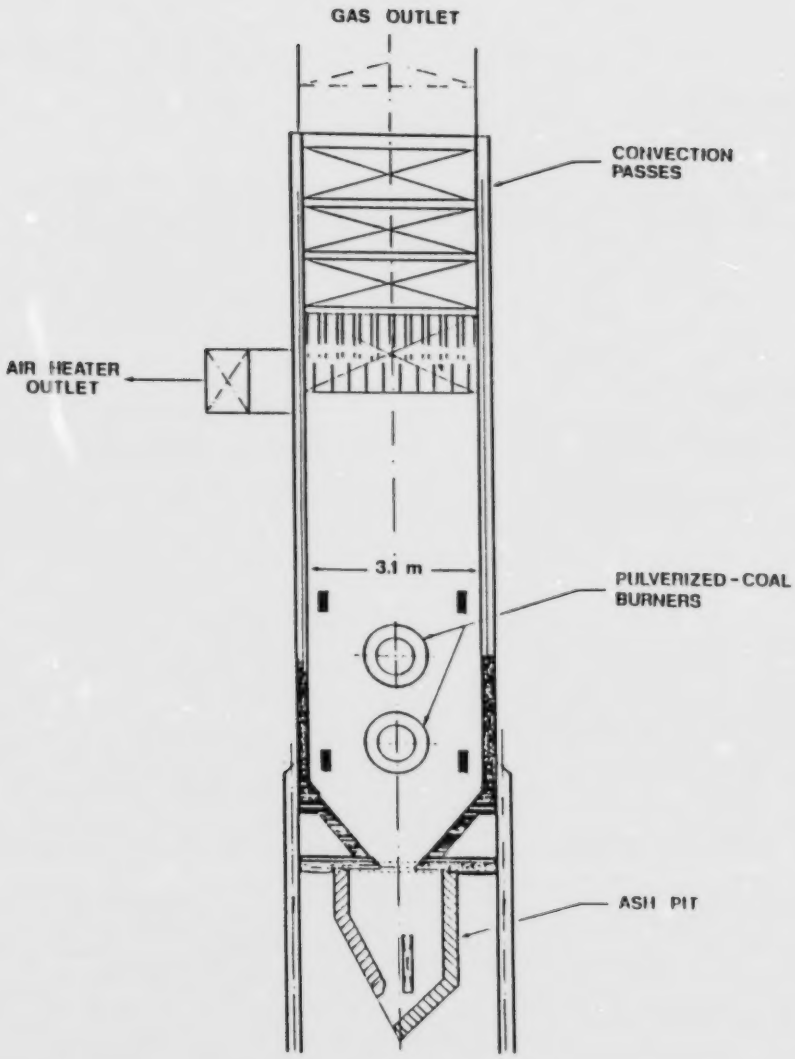


Fig. 2 - Front View: No.2 Generator – Gagetown CHP

Flue gases leave the furnace at about 350°C and pass through an air preheater, a cyclone and an expansion chamber before entering a tall stack at about 200°C. Further information is given in Table 1.

Table 1 - Generator data

Unit	Gagetown No. 2
Rating	70 x 10^6 Btu/h
Type	High-temperature hot water
Initial operation	December 1954
Manufacturer	Combustion Engineering Canada
Design coal	6% sulphur, New Brunswick bituminous
Gas temperature	Entering airheater, 400°C max
Water temperature	Entering generator, 140°C
	Leaving generator, 185°C
Water pressure	1090 kPa
Coal mills	2 at 1.5 tons/hour each
Soot blowers	Furnace walls
	Convective furnace zone
Air temperatures	Induced draft fan, inlet 20°C
	Induced draft fan, outlet 24°C
	Air heater outlet, 200°C

BURNER CONCEPT AND THEORY

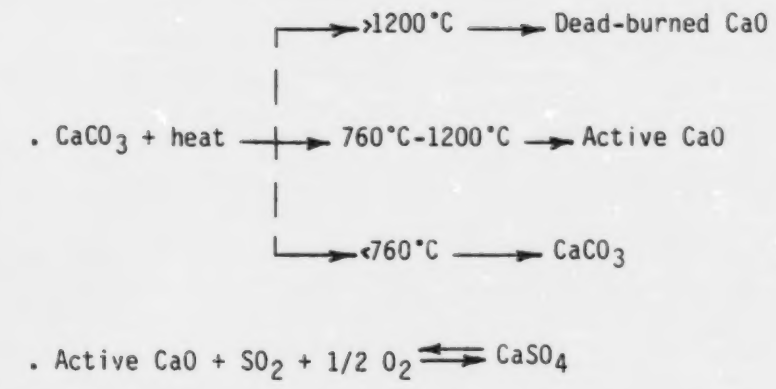
The acid rain precursors, sulphur oxides (SO_x) and nitrogen oxides (NO_x), are generated during pulverized coal combustion via the following basic reactions:

1. combustion air ($N_2 + O_2$) $\longrightarrow$ NO_x
2. coal (N+S+O) $\longrightarrow$ $NO_x + SO_x$
   - coal volatiles $\longrightarrow$ High ($NO_x + SO_x$)
   - char $\longrightarrow$ Low ($NO_x + SO_x$)

The coal accounts for all of the SO_x and between 70% and 80% of the NO_x generated; the balance of the NO_x is derived from the combustion air, and is commonly called thermal NO_x.

The nitrogen oxides from coal combustion can be reduced significantly by staging the burner air to provide a fuel-rich or reducing flame core for conversion of volatile fuel nitrogen to N_2 rather than NO and an air-rich outer flame zone to complete char burnout with minimal production of thermal NO_x. Sulphur oxides are captured by injecting limestone into the air-rich or oxidizing flame zone. These acid gas suppression processes are illustrated below:

$$\text{Coal} + O_2 + \text{heat} \begin{cases} \text{reducing} \longrightarrow \underset{\text{(Volatile)}}{HCN + NH_m + NO} \longrightarrow N_2 + NO_x \\ \text{oxidizing} \longrightarrow \underset{\text{(Char)}}{N + O_2} \longrightarrow NO_x \\ \text{oxidizing} \longrightarrow SO_2 + SO_3 = SO_x \end{cases}$$



. Active CaO + SO_2 + 1/2 O_2 $\rightleftharpoons$ $CaSO_4$

The optimum temperature for calcination of $CaCO_3$ and the subsequent reaction of active CaO ranges from about 760°C to 1200°C. Gas temperatures above or below this range result in either dead-burning or partial decalcination respectively, resulting in poor reaction of calcium with sulphur. Figure 3 shows the structure of flames produced by conventional (unstaged) and staged wall-fired burners.

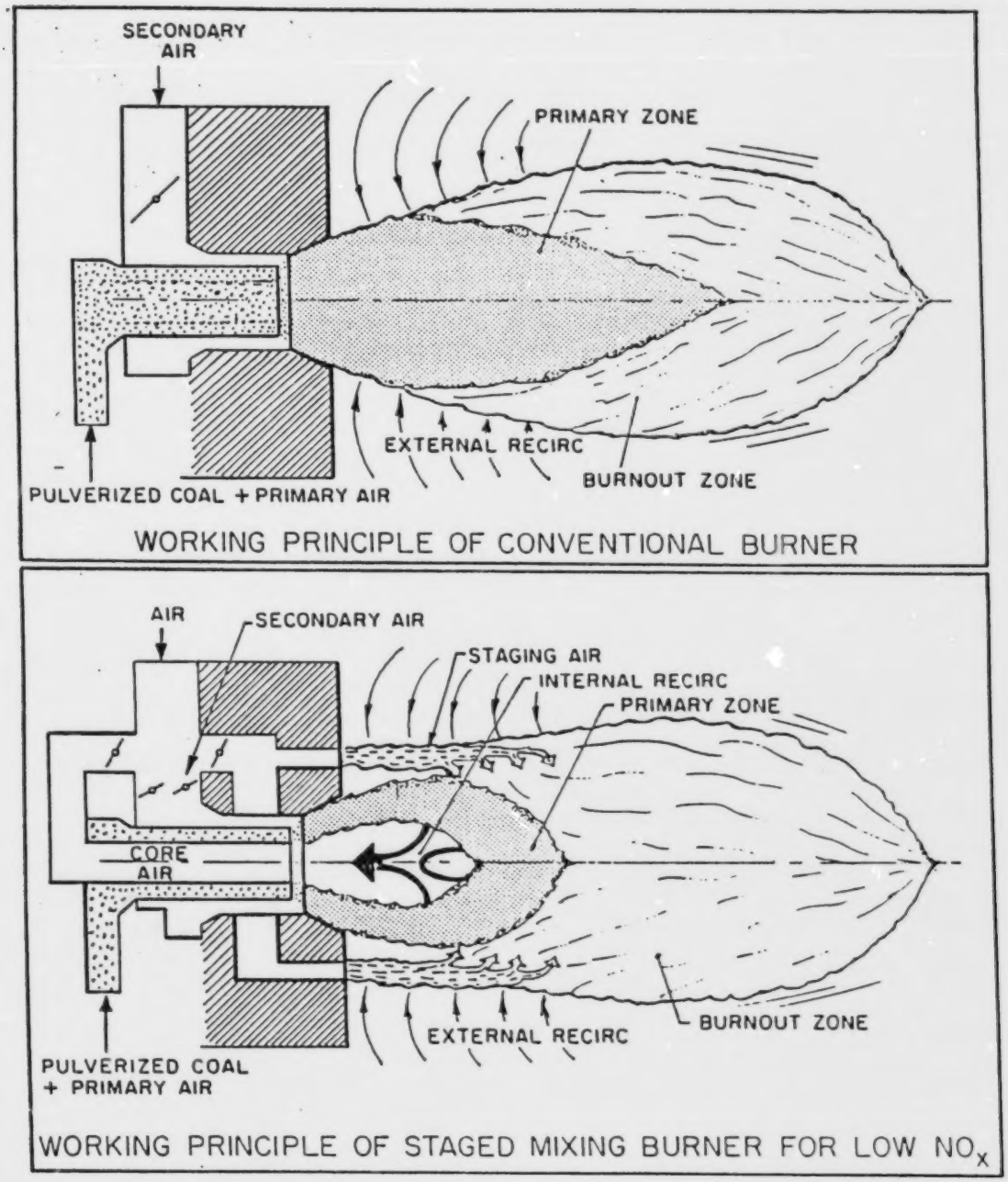


Fig. 3 - Conventional and staged flame principles

DESIGN AND PERFORMANCE SPECIFICATIONS

The limestone injection multi-staged burner (LIMB) was designed to operate with the coal and the additive compositions given in Tables 2 and 3 respectively. Under full load conditions, the burner performance was specified as follows:

a) NO_x reduction 50% minimum;

b) SO_x reduction 50% minimum at a Ca/S mol ratio = 2.5/1;

c) carbon in ash 7% maximum;

d) generator efficiency 80% minimum;

e) no furnace slagging;

f) no flame impingement on furnace walls.

The above design and performance specifications were considered to be both realistic and achievable following a series of baseline tests with the unmodified burners in March 1982 using coal alone and coal pre-blended with a local limestone. Figure 4 shows the location of the emissions sampling station used during both the baseline tests and the later series of tests with the staged burners.

Table 2 - Coal analysis

a)	**Proximate:**		
	Moisture	%	10
	Volatile matter	%	30
	Fixed carbon	%	51
	Ash	%	9
	Net calorific value	MJ/kg	28.78
	Spec. air requirement	kg/kg	9.20
b)	**Ultimate:**		
	Carbon	%	75.2
	Hydrogen	%	4.8
	Sulphur	%	3.0
	Nitrogen	%	1.4
	Ash	%	10.0
	Oxygen (diff.)	%	5.6
c)	**Sulphur forms:**		
	Sulphate	%	0.4
	Pyrite	%	1.8
	Organic (diff.)	%	0.8

Table 3 - Additive analysis

Range of molar ratio Ca/S		1 to 4
Flow range	$Ca(OH)_2$	4.61 l/min - 36.9 l/min
	$CaCO_3$	2.48 l/min - 19.85 l/min
CaO content of $Ca(OH)_2$		74%
CaO content of $CaCO_3$		55%

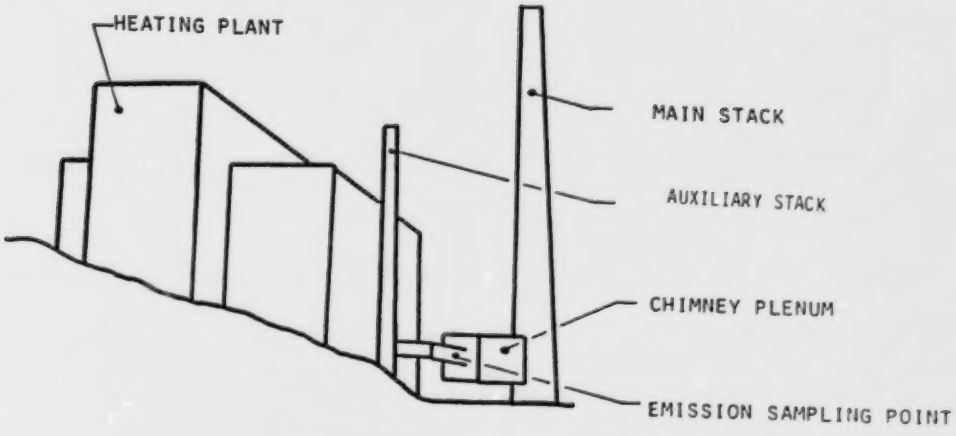
Bulk density:

$Ca(OH)_2$	400 kg/m^3
$CaCO_3$	1000 kg/m^3

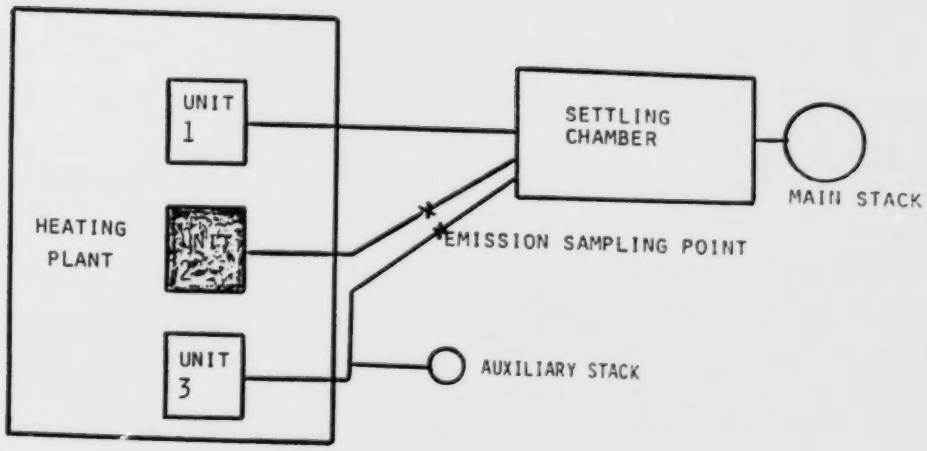
Particle size distribution:

$Ca(OH)_2$:	aerodynamic separation	
	greater than 200 x 10^{-6} m	0%
	63	2.2%
	32	12.0%

$CaCO_3$:	aerodynamic separation	
	greater than 200 x 10^{-6} m	0%
	63	14.4%
	32	25.8%



OUTSIDE VIEW OF PLANT



PLAN VIEW OF PLANT

Fig. 4 - Gagetown Central Heating Plant showing generator layout and location of emissions sampling point

COMBUSTION SYSTEM DESCRIPTION

The low NO_x/SO_x burner technology which was retrofitted on Generator No. 2 during the autumn of 1983 consisted of two pulverized coal burners with external tertiary air ports, and systems for a) ignition and burner management, b) combustion air distribution and c) limestone, metering and furnace injection. The layouts of the main flow circuits for the combustion air and additive injection systems are shown in Figures 5 and 6. Some design data of the burner and additive systems are given below:

a)	Burner		
	Temp. after mill	°C	90
	Temp. before mill	°C	272
	Hot air temp.	°C	180
	Gas/coal ratio	kg/kg	1.5
	Excess air ratio		1.25
	Total fuel flow rate	kg/s	0.868
b)	Additive injection system		
	Bin capacity	m^3	100
	Bin diameter	mm	3100
	Bin overall height	mm	17000
	Pneumatic ejector capacity	kg/h	1200/600

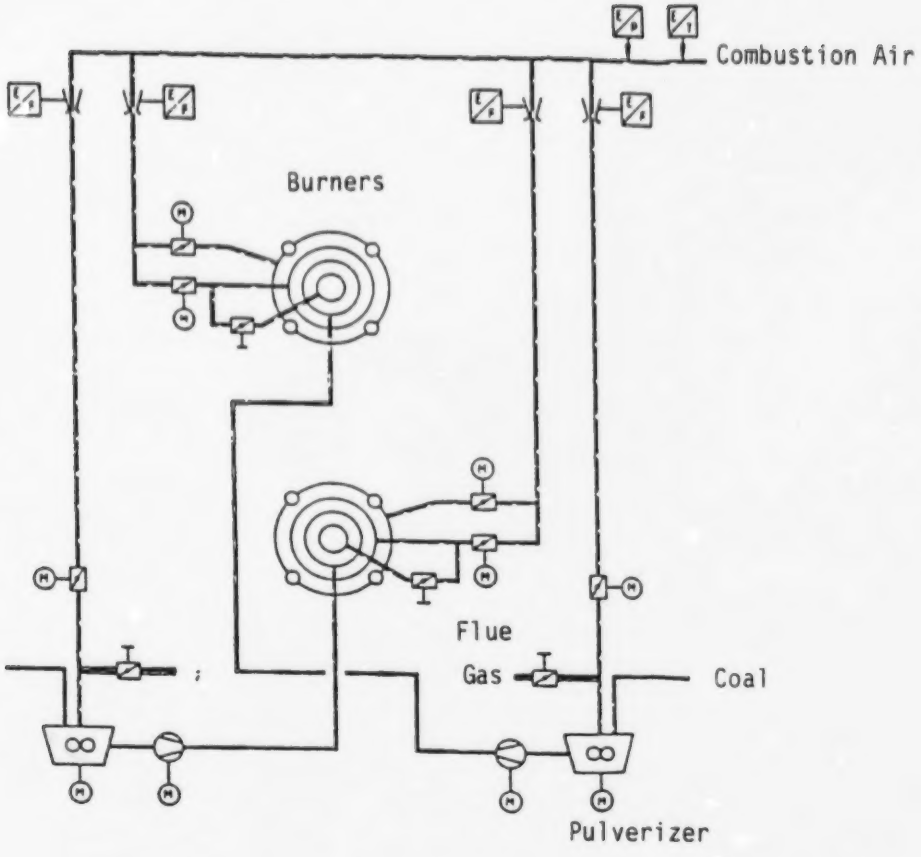


Fig. 5 - Combustion air and pulverized coal supply system

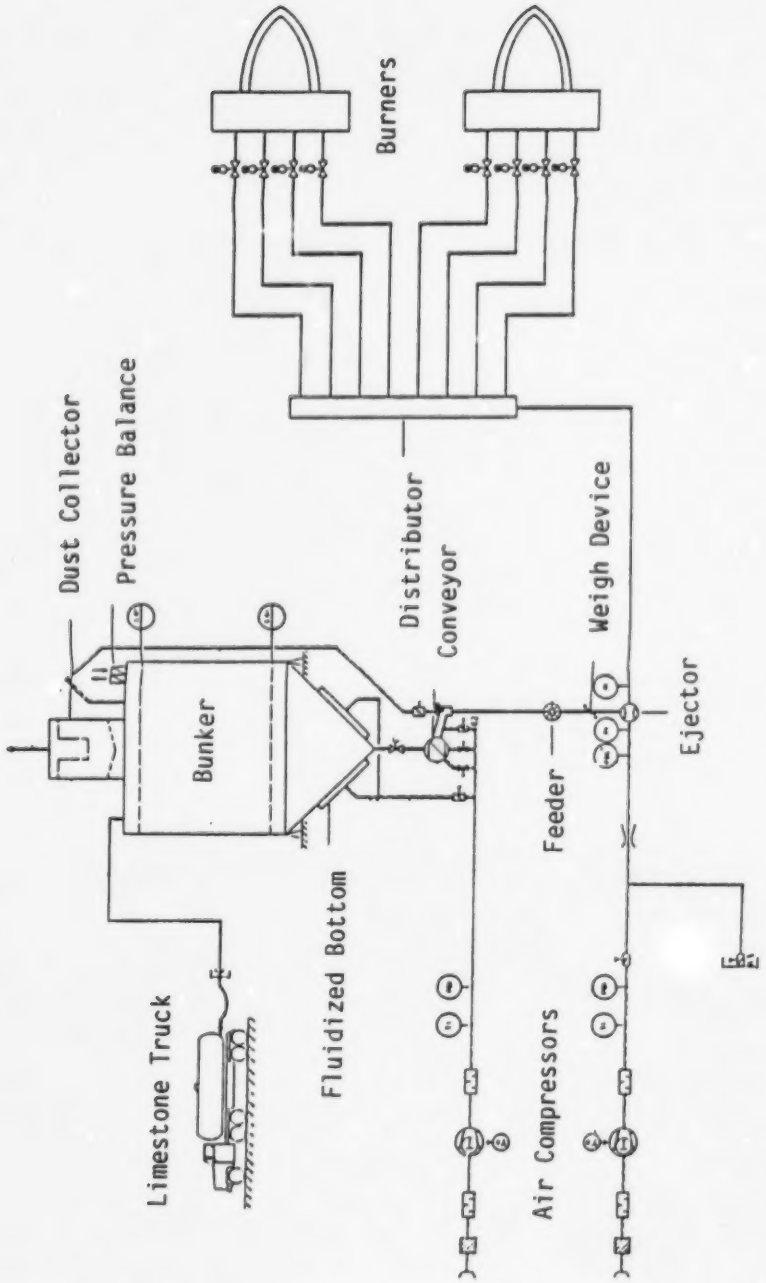


Fig. 6 - Limestone injection system

BASELINE TESTS

Emissions measurements were taken on Generator No. 3 in March 1982 to obtain baseline data against which the performance of the new burner equipment could be compared. Combustion tests were conducted at full and one-half load burning coal only and coal blended with limestone. The coal contained 2.6% sulphur and 8.4% ash, and the limestone was metered into the coal feed to the pulverizer.

Table 4 shows that the average levels of NO_x and SO_x for coal only at full load were 590 ppm and 1970 ppm respectively when adjusted to 3% O_2 in the flue gas. The addition of limestone to the coal at a Ca/S ratio of 3.25 resulted in a 35% reduction in SO_2, but a 22% increase in NO_x at full load. This increase in NO_x was probably due to the change in furnace wall absorptivity and the use of less oil support during the additive tests.

Table 4 - Baseline test data*

Load	Ca/S	O_2%	NO_x ppm	SO_2 ppm
Half	-	6.2	420	1990
Half	3.25	7.2	420	1200
Full	-	6.0	590	1970
Full	2.72	6.3	750	1330
Full	3.5	6.5	720	1280

*NO_x and SO_x corrected to 3% O_2 in the flue gases

COMMISSIONING TESTS

The initial commissioning tests were carried out in November 1984 on two coals respectively containing 3.5 and 1.5% sulphur, and 6.7 and 6.0% ash. The burner management system, oil ignition equipment, and limestone injection system performed satisfactorily, while 50% reductions in both NO_x and SO_x were achieved. However, serious operational difficulties were experienced with:

a) carbon carryover;

b) poor ignition;

c) flame pulsations; and

d) limestone metering.

A subsequent inspection of the burners showed that the refractory quarls had not been contoured as specified. The quarls were re-cast to the required specifications during January 1985. However, additional commissioning trials conducted in March 1985, employing the new quarls and an intermediate swirl setting, were unsuccessful in resolving the problems described above. Further observations during April 1985 showed:

a) no improvement in flame stability;

b) no flame between 11:00 and 1:00 h when the quarl was viewed from the rear wall;

c) flame impingement and a sintered buildup of ash on the quarl between 5:00 and 8:00 h;

d) continuous oil support needed to avoid flame failure;

e) flame pulsations that resulted in flue gas leakage into the operating room; and

f) excessive carbon carryover.

Table 5 summarizes the test measurements from both commissioning periods. These were performed with a coal fineness of 85% less than 200 mesh. NO_x and SO_2 reductions met or exceeded 50%, but carbon in fly ash remained unacceptably high at 52 to 68%.

Table 5 - Commissioning test data*

Boiler No.	Coal % S	Load	Ca/S	O_2 %	NO_x* ppm	SO_2*	Fly ash g/m^3
2	3.5	Full	-	4.9	245	2453	4.2
2	3.5	Full	3.2	5.6	254	1136	10.3
2	3.5	Half	-	6.4	228	2585	3.9
2	3.5	Half	2.7	5.8	197	1333	7.7
2	1.6	Full	-	6.4	248	1117	4.0
2	1.6	Full	3.0	5.3	211	658	6.0
1**	3.5	Full	-	5.0	567	2087	3.4
1**	3.5	Half	-	9.4	404	1807	-

* NO_x and SO_2 adjusted to 3% O_2 in the flue gases and fly ash loading adjusted to 25°C and 101.3 kPa.

** Conventional coal burners.

MODIFIED BURNER TESTS

During the summer of 1985, the contractor recommended four design changes to correct the poor performance of the retrofitted burners. These modifications, the first three of which are shown in Figure 7, were:

a) a reduction in the outside diameter of the core air pipe to decrease the primary air velocity;

b) installation of a swirl vane in the annular exit of the coal pipe to improve flame recirculation;

c) installation of deflectors on each of the four tertiary air ports to direct more air into the primary flame zone; and

d) installation of supplementary oil-fired heaters in each of the primary air ducts upstream of the pulverizers to obtain the required air preheat.

It was anticipated that these changes would improve flame stability and reduce carbon carryover with a corresponding but acceptable increase in NO_x emissions. The performance of the modified burners was evaluated in early December 1985 using a coal with 2.4% sulphur and 9.9% ash. A marginally hotter flame was produced with slightly less carbon in ash relative to the commissioning tests; but NO_x levels increased by about 50% and flame impingement occurred on the rear furnace wall. Results of these tests are given in Table 6.

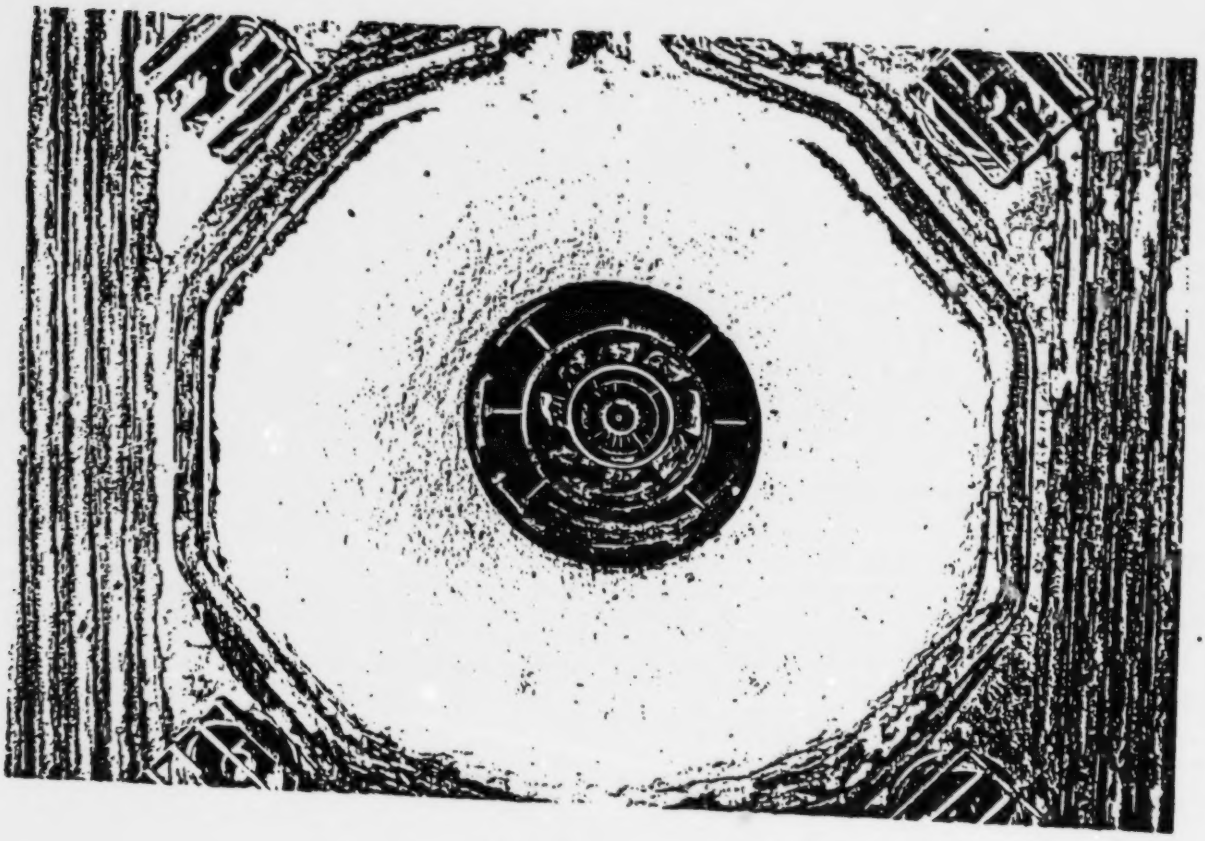


Fig. 7 - Modified burner showing coal swirler, tertiary air deflectors and smaller core air pipe

Table 6 - Modified burner tests*

Load	Ca/S ratio	O_2 %	NO_x ppm	SO_2 ppm	C in Ash %
Half	-	7.8	475	1088	40
Half	1.2	8.3	472	630	
Half	2.6	8.2	470	449	
Full	-	4.5	384	1167	50
Full	1.4	5.4	339	881	33
Full	2.0	5.9	309	712	21

* NO_x and SO_2 corrected to 3% O_2 in the flue gases

Operation of the modified burner through the remainder of December 1985 until mid-January 1986 resulted in a steady deterioration in burner performance that manifested itself in:

a) increased frequency and intensity of flame pulsations;

b) increased carbon carryover;

c) a fire in the furnace ash hopper due to unburned coal;

d) leakage of flue gas into the boiler operations area;

e) coke and sintered ash deposits on the quarls; and

f) flame impingement and erosion on the rear furnace wall.

These problems resulted in a decision to take Generator No. 2 out of service and to investigate available corrective measures. Consequently, eight courses of action were decided upon:

a) removal of the swirl vanes from the coal annulus and oil gun and removal of the deflectors from the tertiary air ports;

b) conduct a mathematical modelling study of Generator No. 2 to determine the major parameters influencing carbon burnout;

c) installation of a burner tip to reduce the exit velocity of the primary air, to produce a "bluff body" effect for flame stabilization and to ensure uniform distribution of coal around the primary air annulus;

d) installation of sight ports in the rear walls, side walls and roof of the furnace to permit viewing the flame while swirl and combustion airflows are being adjusted;

e) replacement of the slide dampers on the eight limestone injection lines with ball valves;

f) installation of a pressure balancing valve in the chamber under the impact plate of the limestone weighing device;

g) installation of a rotary seal between the pressure balancing valve and the limestone injector; and

h) removal of the supplementary oil-fired primary air heaters.

FURNACE MODELLING STUDIES

A three-dimensional modelling study of Generator No. 2 with the staged burners was conducted during 1986 to assist in delineating the input conditions for optimal combustion performance and minimal carbon carryover. The model, developed by Richter (1), simulates radiative heat transfer between the zones shown in Figure 8 using the Monte Carlo technique, and is directly coupled to a coal combustion code to determine the heat release distribution within each zone. Volatile matter is assumed to be released instantaneously and to burn in accordance with an exponential function. The

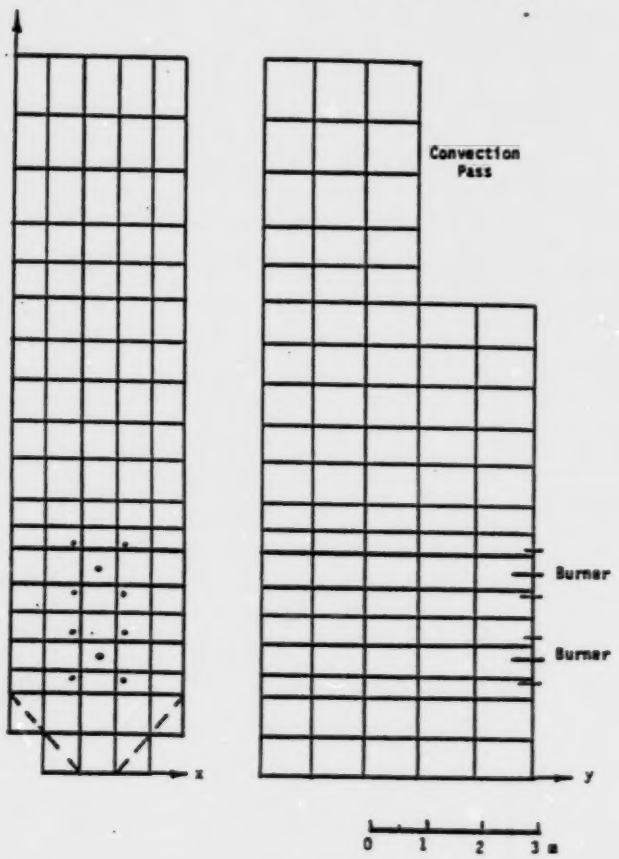


Fig. 8 - Zone arrangement for heat transfer modelling of Gagetown boiler

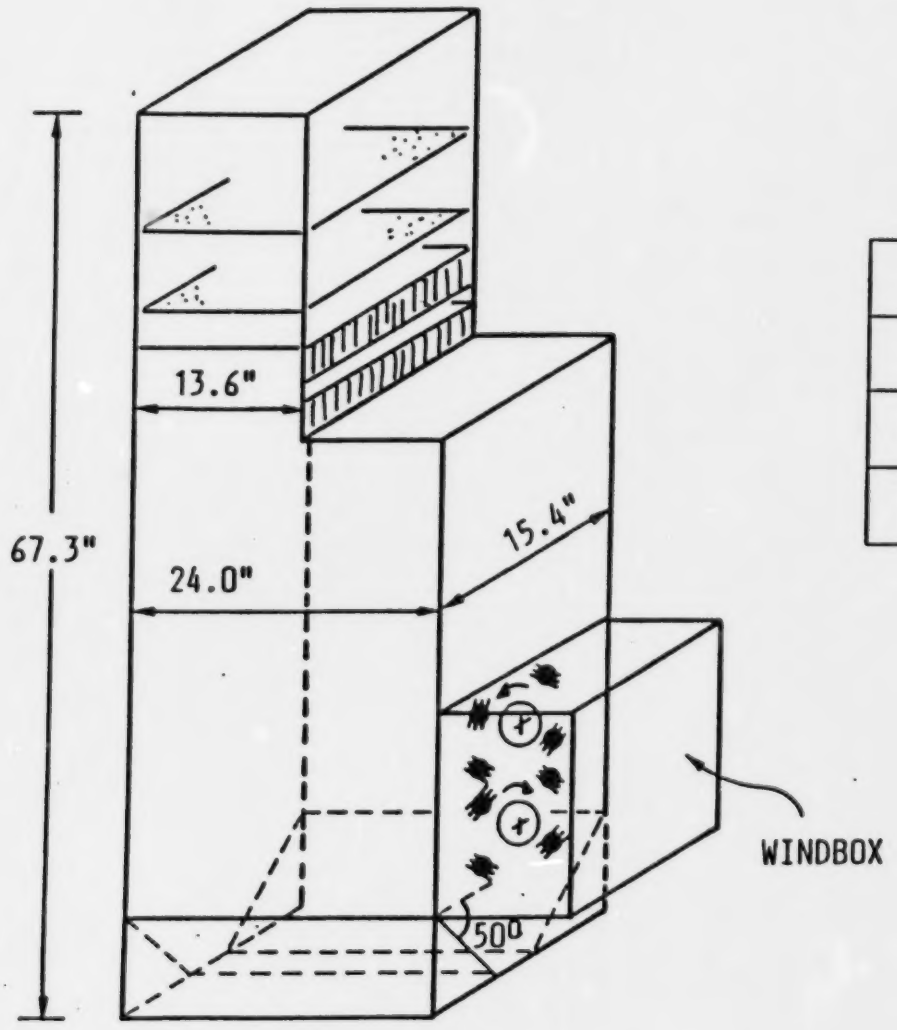
(1) Richter, W., Scale-up and Advanced Performance Analysis of Boiler Combustion Chambers, 1985 ASME Winter Annual Meeting, Paper 85-WA/HT-80

heat release from char is determined from a mass balance of 10 particle size fractions and the available oxygen in each zone.

Mass fluxes for each zone were obtained from a 1/8 - scale cold model of the furnace (Figure 9) using burner dimensions based on the Thring-Newby criteria. A comparison of the flow velocities measured at the centreplane of the cold model with streaklines generated by injecting helium bubbles through a burner is shown in Figure 10. The flow pattern shows a strong recirculation eddy in both the upper furnace and the furnace hopper.

The input data given in Tables 7 and 8 were used to compute the gas and surface temperature in the furnace, the total heat flux densities and the carbon burnout profiles shown in Figure 11 to 16 inclusive. The four furnace conditions were insensitive to most parameters except for coal reactivity. The predicted axial temperature profiles through the furnace for each input condition (Figure 17) showed good agreement with the three measured data points.

Table 9 indicates that the carbon in ash should range from about 12 to 21% for a high-volatile coal containing 10% ash and Figure 18 shows that maximum sulphur capture should vary from about 25 to 37% depending on the coal sulphur content.



GEOMETRIC SCALE FACTOR	1/8
TOTAL FLOW RATE	300 SCFM
R_{EH} AT FURNACE PLANE	18,900
R_{EH} AT NOSE PLANE	25,700

Fig. 9 - Overall dimensions of 1/8-scale cold model

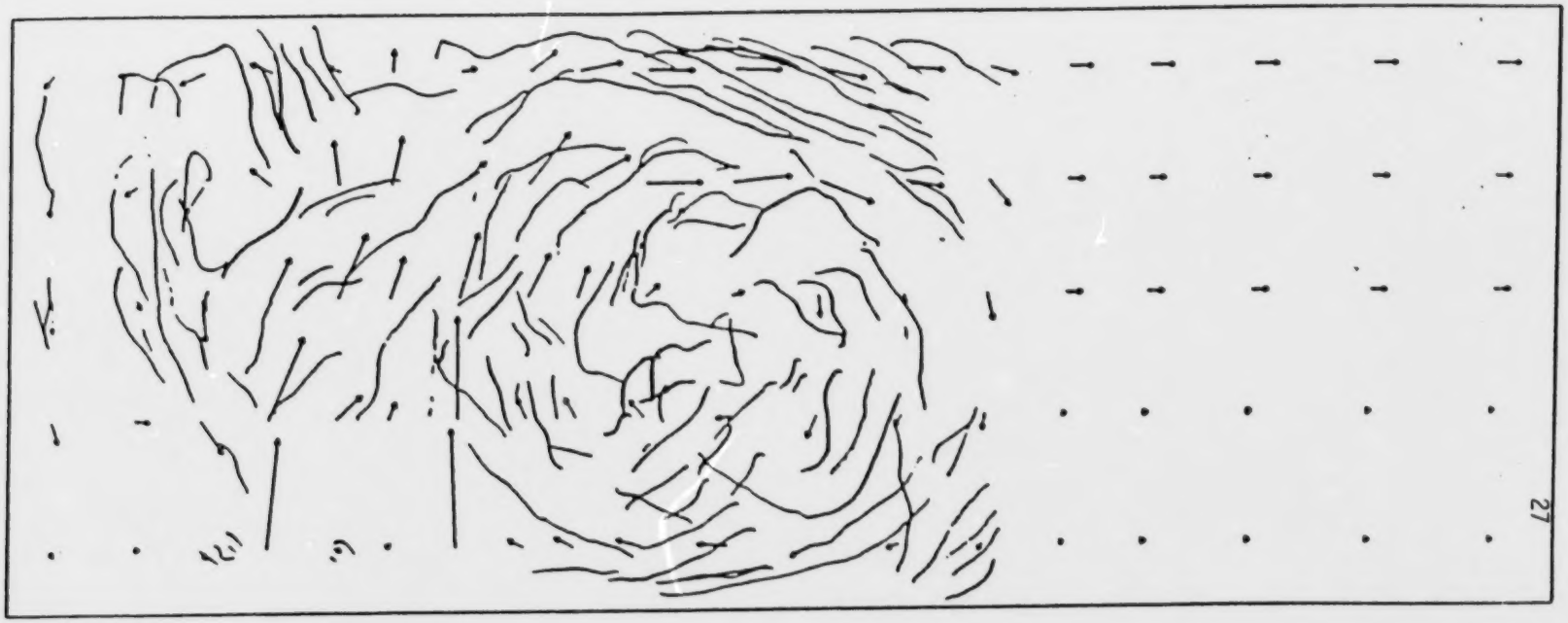


Fig. 10 - Comparison of measured flow velocities with streaklines at the centreplane of the cold model

Table 7 - Operating conditions assumed for heat transfer modelling study

Coal flow	0.6864 kg/s			
No. 2 oil flow	0.0218 kg/s			
Coal analysis:	Proximate kg/kg_{wet}		Ultimate kg/kg_{wet}	
	FC	0.5434	C	0.7105
	VM	0.3621	H	0.0502
	H_2O	0.0179	N	0.0126
	Ash	0.0766	O	0.0978
			S	0.0344
			Ash	0.0766
			H_2O	0.0179
Higher heating value of coal:	31 562 kj/kg_{wet}			
Upper heating value of oil:	45 154 kj/kg_{wet}			
Initial coal size distribution:	80.0 wt%	74 x 10^{-6}m		
	92.6 wt%	149 x 10^{-6}m		
	98.5 wt%	257 x 10^{-6}m		
Excess air:	20.36%			
Secondary and tertiary air temperature:	483 K			
Primary mixture temperature:	376 K			

Table 8 - Burner parameters assumed for heat transfer modelling study

Case No.	Case Description	Net Fuel Heat Input	Excess Air	Prim. Air Flow Rate	Sec. Air Flow Rate	Tert. Air Flow Rate	Prim. & Sec. Burner Zone Stoichiom.	Frequency Factor for Char Reaction	COMMENTS
		kW	%	kg/s	kg/s	kg/s		$\frac{kg_C}{m^2 s\ bar\ O_2}$	
1	Uniform stoichiometry of burner zones	21839	20.36	0.9586	5.2875	2.1100	1.2036	1200	Fuel was assumed to enter through tert. air port
2	Non-uniform burner zone stoichiometry, high char reactivity	21839	20.36	0.9586	5.2875	2.1100	0.8337	1200	
3	As in Case 2 but low char reactivity	21839	20.36	0.9586	5.2875	2.1100	0.8997	600	
4	Non-uniform burner zone stoichiometry, reduced tert. air	21839	20.36	0.9586	5.7658	1.6316	0.9686	1200	Close to conditions of Test 1, Nov. 84

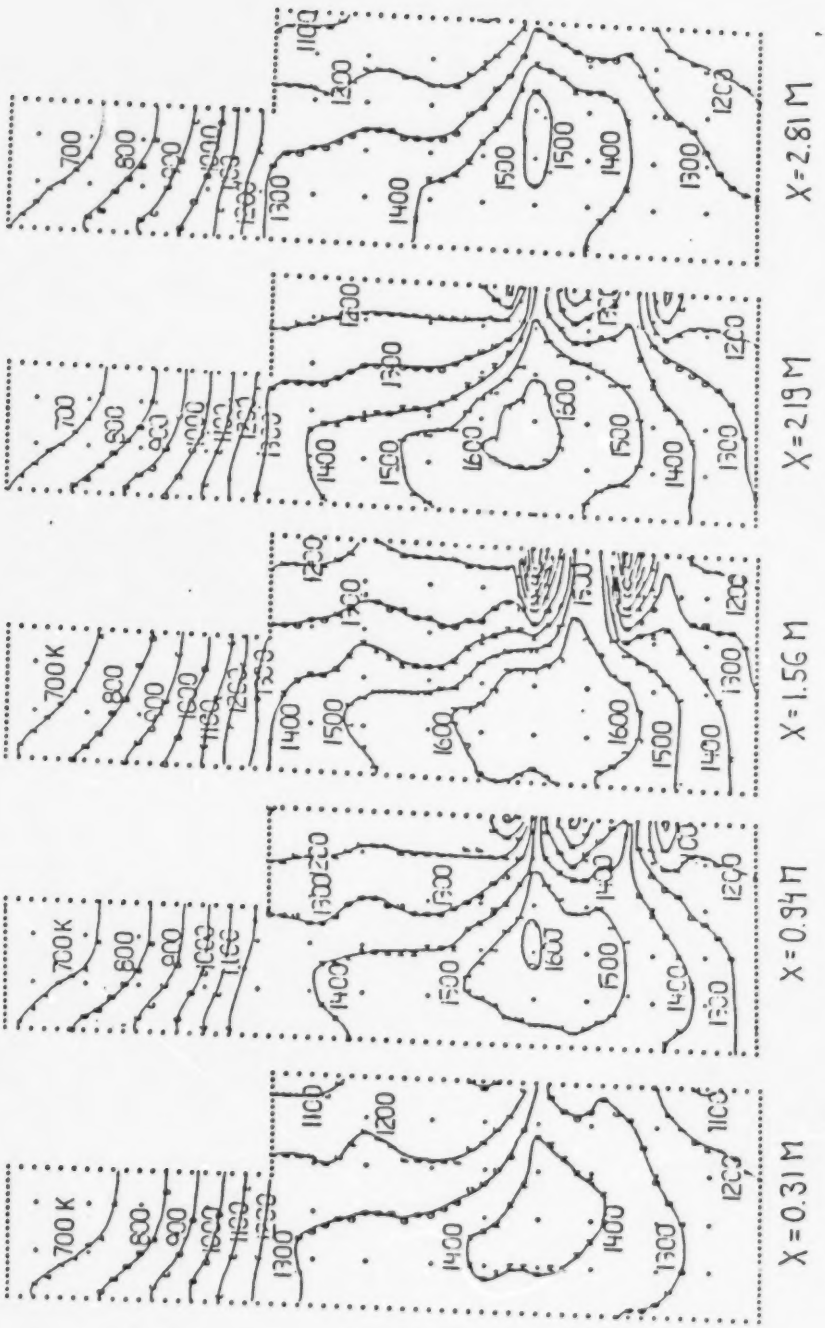


Fig. 11 - Case 2: Gas temperatures, K

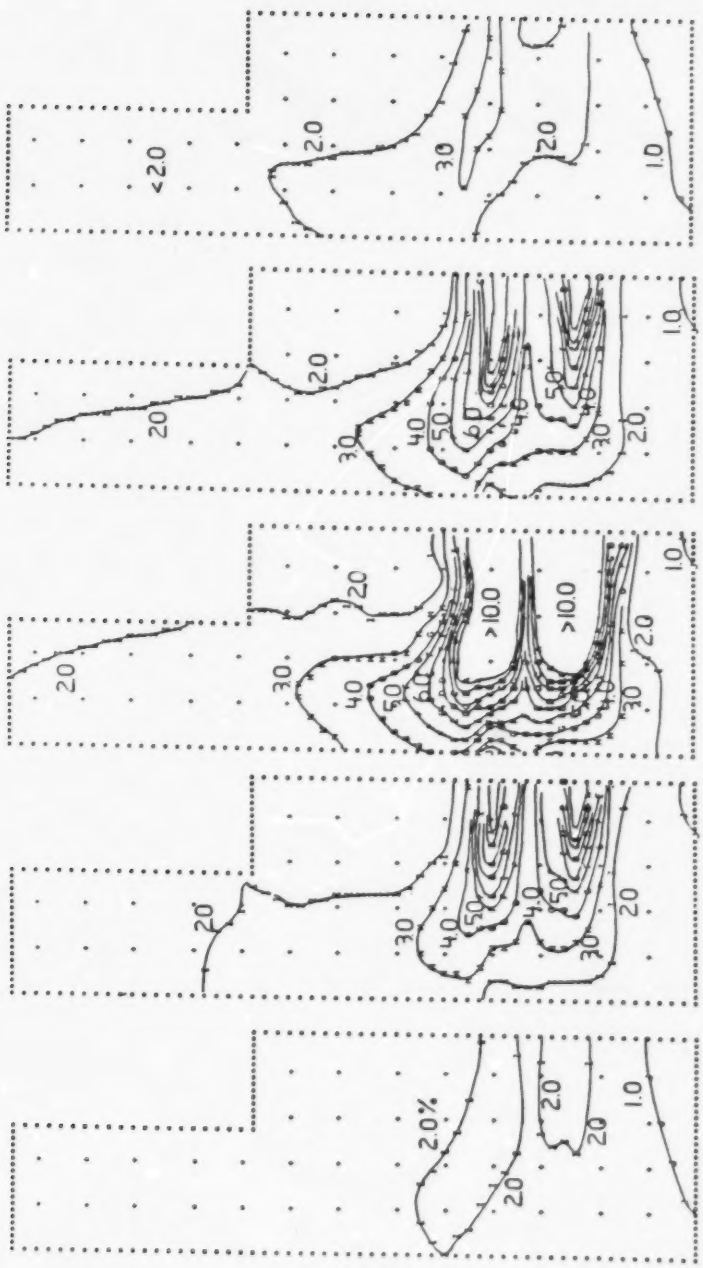


Fig. 12 - Case 2: Unburned fixed carbon (% of input value)

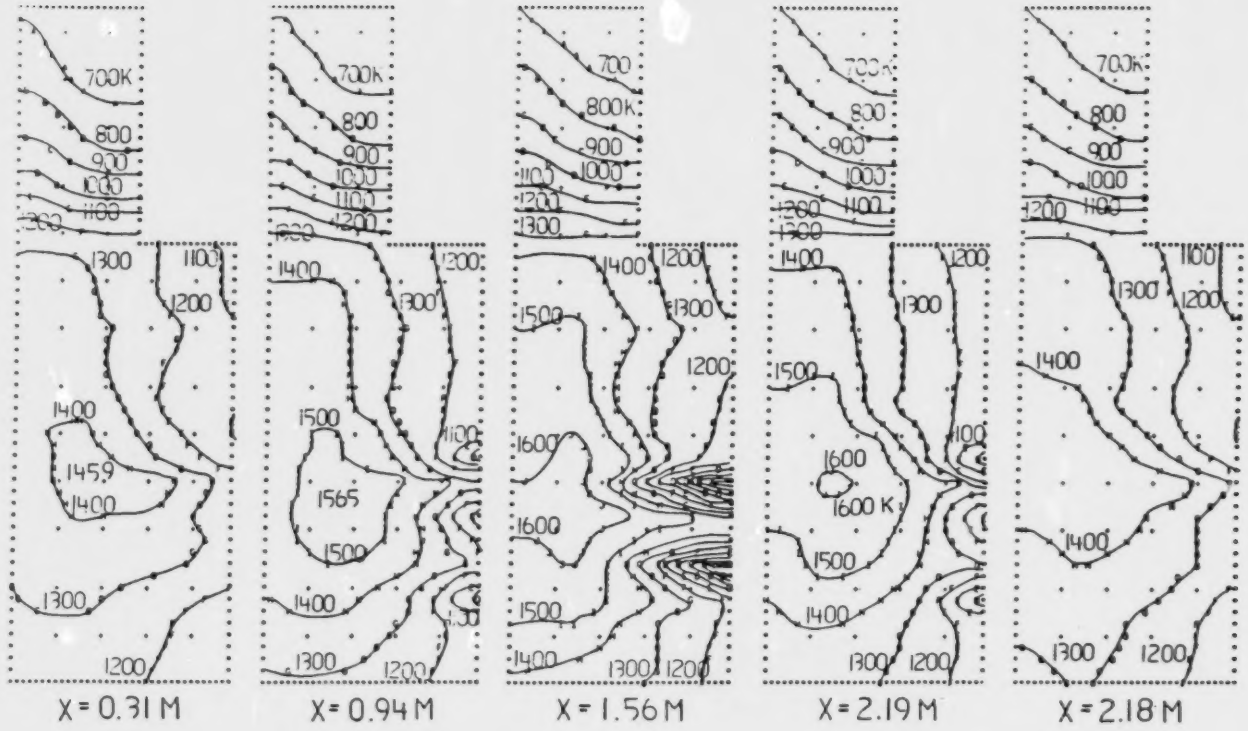


Fig. 13 - Case 3: Gas temperatures, K

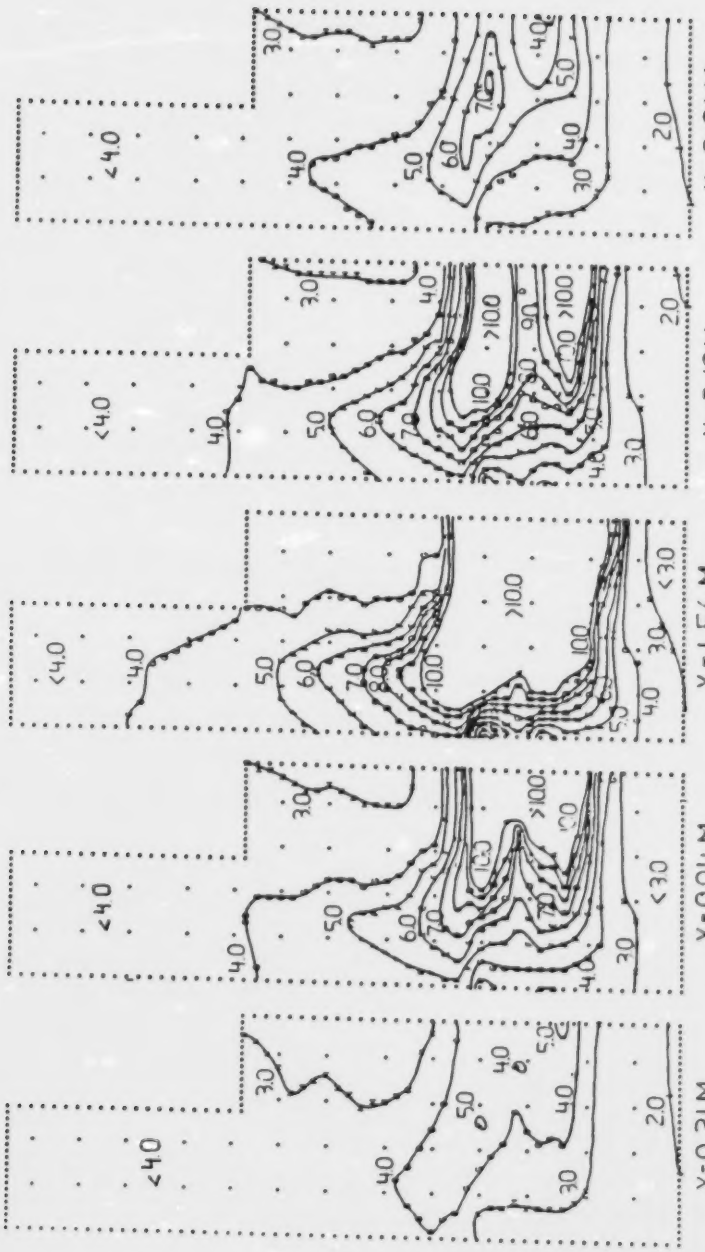


Fig. 14 - Case 3: Unburned fixed carbon (% of input value)

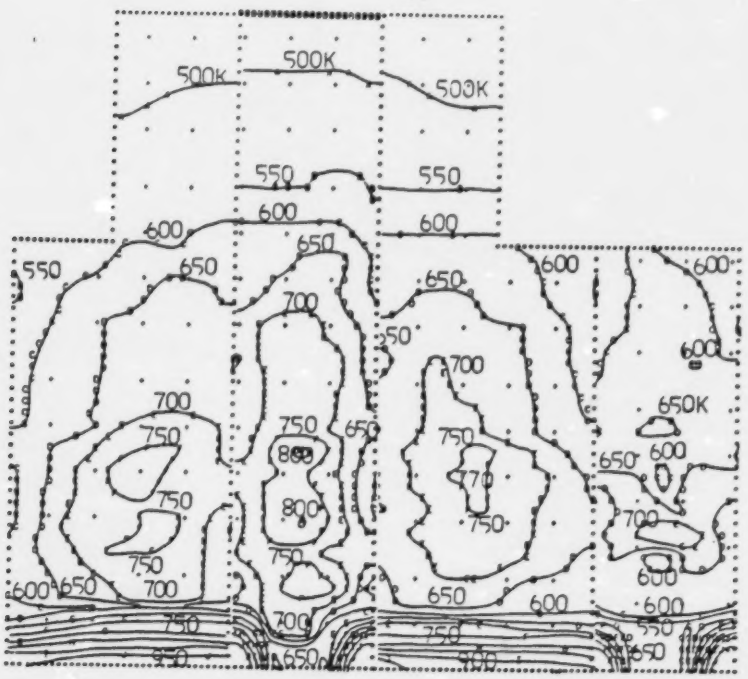


Fig. 15 - Case 3: Surface temperatures of deposits, K

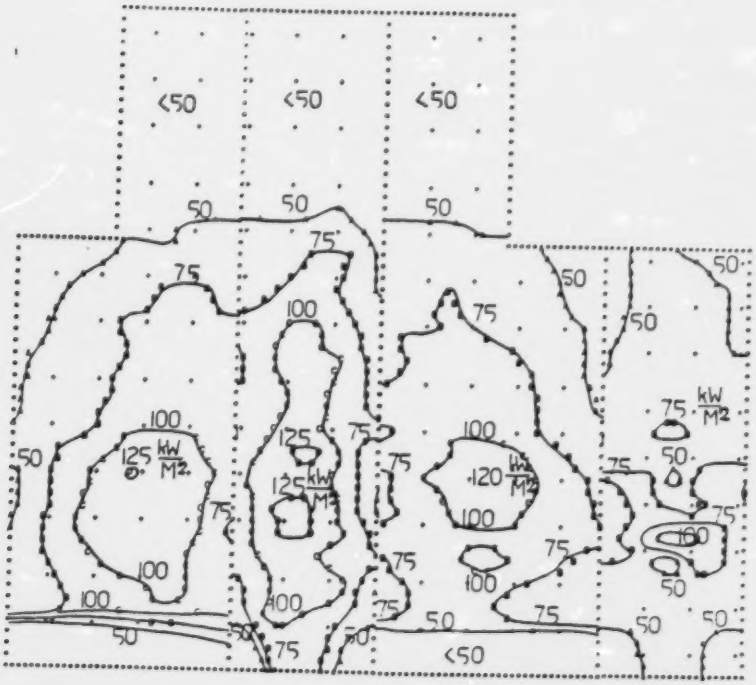


Fig. 16 - Case 3: Total net heat flux densities, kW/m^2

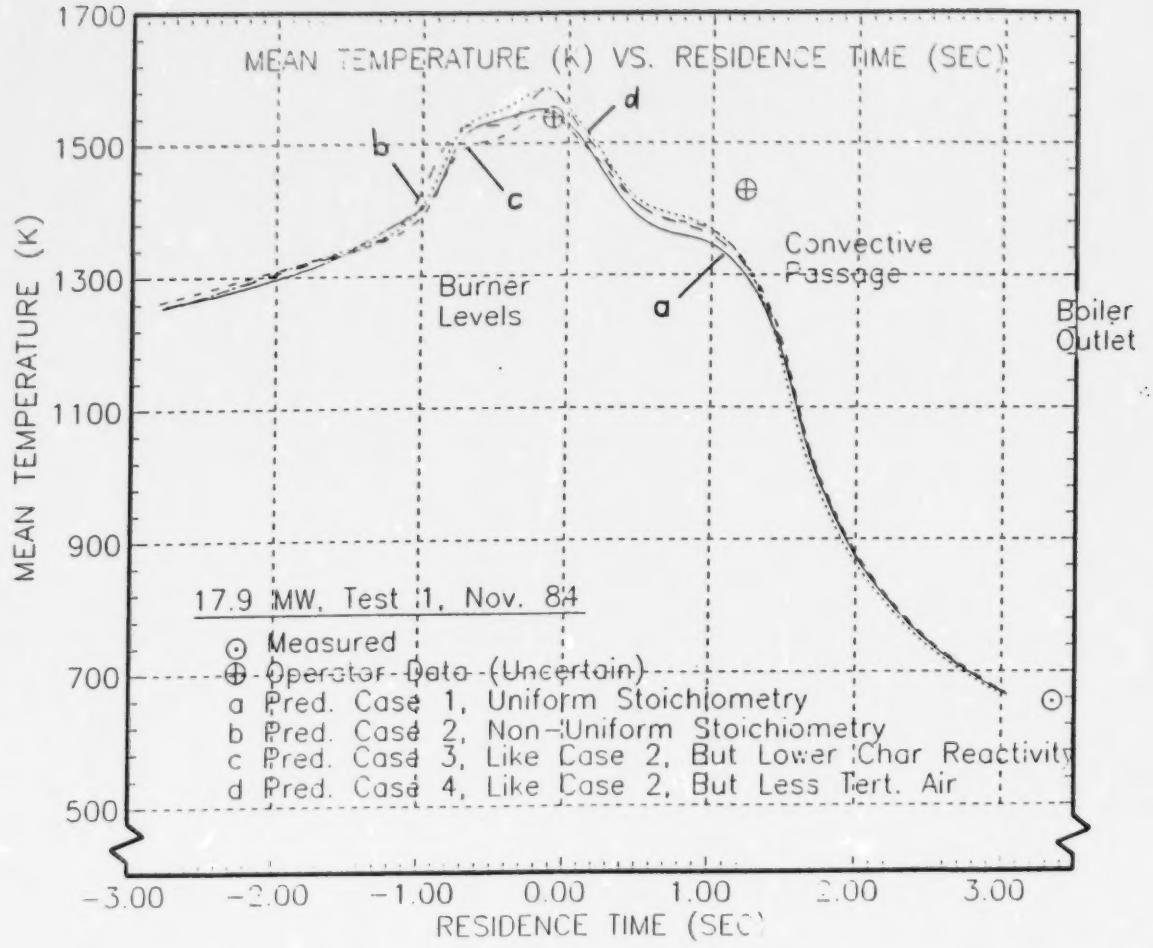


Fig. 17 - Predicted and measured axial temperatures in Generator No. 2

Table 9 - Boiler performance predicted from modelling study

Case No.	Case Description	Net Total Heat Release (NTHR)	Furnace Efficiency Based On NTHR	Boiler Efficiency Based On NTHR	Gross Boiler Efficiency	Furnace Exit Temp.	Boiler Exit Temp.	Max Flame Temp.	Max Dep. Temp.	Max. Inc. Radiative Heat Flux	Carbon in Ash
		kW	%	%	%	K	K	K	K	kW/m^2	%
1	Uniform stoichiometry of burner zones	23074	52.85	84.08	86.08	1324	664	1623	789	192	12.96
2	Non-uniform burner zone stoichiometry, high char reactivity	23105	52.16	84.38	86.08	1337	666	1701	793	195	12.14
3	As in Case 2 but low char reactivity	22877	51.36	83.04	83.87	1344	669	1665	809	205	21.09
4	Non-uniform burner zone stoichiometry, reduced tert. air	23126	51.69	84.32	86.09	1354	669	1681	787	191	11.20

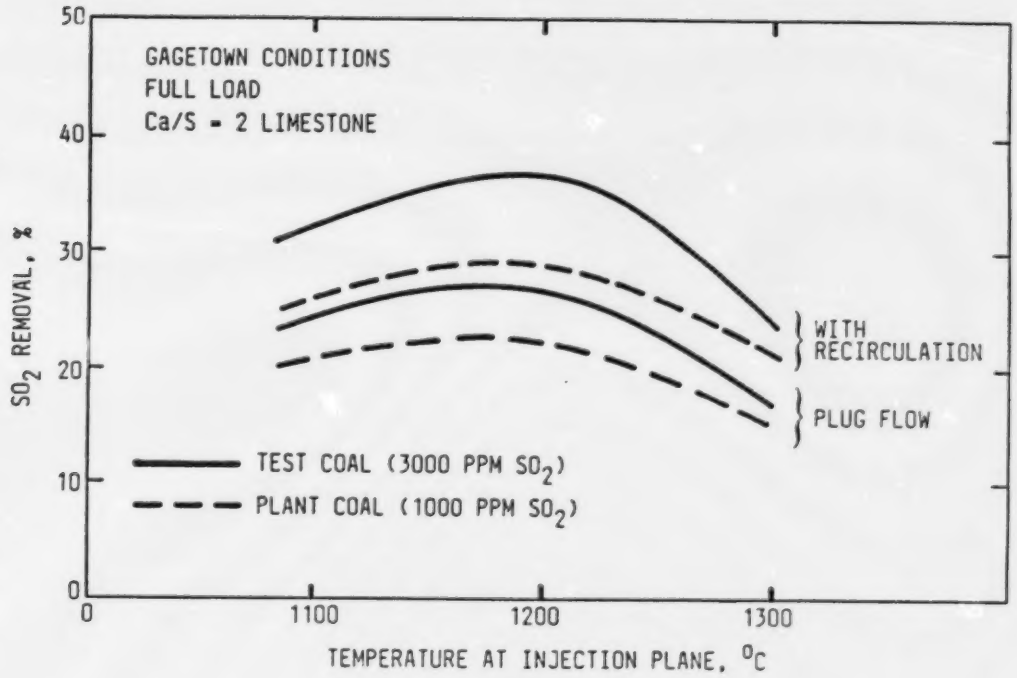


Fig. 18 - Predicted sulphur capture with temperature at the injection plane

DEVELOPMENTAL TESTS

In early 1987, following installation of the sight ports and completion of the modelling study, a series of tests was conducted to assess the operability of the redesigned burner tip and the validity of the model predictions. During these tests in which the fineness of the coal and limestone exceeded 75% less than 75 x 10^{-6} m and 44 x 10^{-6} m respectively as shown in Figure 19, flame stability was achieved by:

a) substantially reducing the airflow through the pulverizer;
b) further increasing the area of the coal annulus;
c) mounting a ring of platelets on the inside surface of the outer coal pipe; and
d) operating with a controllable furnace draft.

The effect of using a high ratio of secondary to primary air is shown in Figure 20. With high primary airflows the size and intensity of the flame recirculation zone decrease resulting in poor flame stability, excessively long flames and high carbon carryover.

The flame shape and length, as viewed through the roof sight port was optimized by reducing the swirl setting from maximum to an intermediate level. All of the above changes were beneficial in that flame pulsations were eliminated, ignition of the coal stream was self supporting, the furnace was again operating under an induced draft and carbon carryover was reduced.

As shown in Table 10, tests were carried out on two Cape Breton coals - a 3.2% sulphur coal containing 10% ash blended from coal rejects which were difficult to burn; and a 1.1% sulphur metallurgical coal containing 3% ash which burned readily. The limestone feedrates surged badly during these tests and consequently were difficult to control even though a pressure balancing valve was installed to equalize the pressure under the weigh plate with the ambient atmosphere.

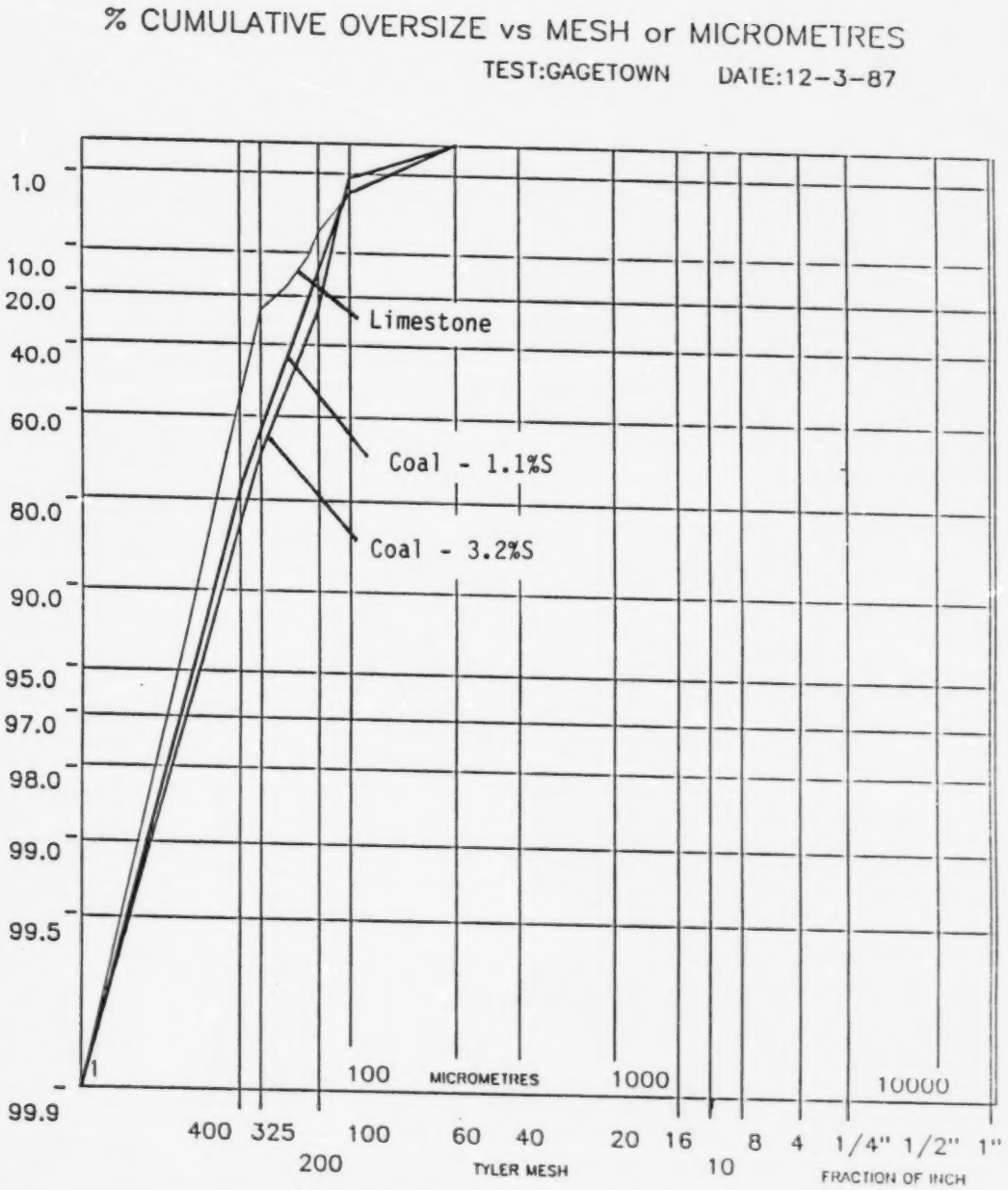
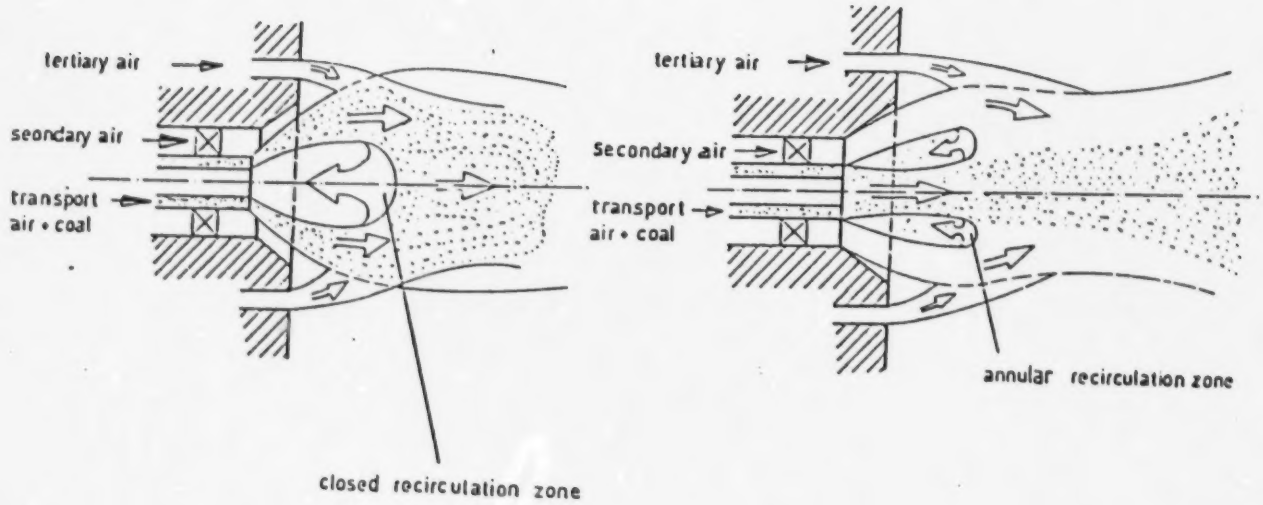


Fig. 19 - Coal and limestone fineness for burner development tests



a) Low primary airflow

b) High primary airflow

Fig. 20 - Influence of primary airflow on the size and intensity of flame recirculation

Table 10 - Burner development tests

Coal %S	Load	Ca/S	O_2 %	NO_x ppm[3]	SO_2 ppm[3]	Heat Loss %C
1.1[1]	Half		4.5	347	827	2.1
1.1	Half		6.2	509	761	1.5
1.1	Half	2.6	5.7	419	249	1.3
1.1	F	-	4.6	400	784	0.5
1.1	F	3.6	4.2	363	357	1.0
3.2[2]	Half	-	4.8	452	2145	
3.2	Half	-	5.6	492	2163	3.9
3.2	Half	2.5	3.9	390	969	
3.2	Half	2.0	3.7	392	953	
3.2	Half	1.4	4.2	391	986	
3.2	Half	3.0	3.2	357	862	1.7
3.2[4]	Half	-	4.9	464	1922	

Note: 1. Tests with 1.1% coal conducted with clean furnace convection passes.

2. Tests with 3.2% coal conducted with uncleaned furnace convection passes;

3. NO_x and O_2 adjusted to 3% O_2 in the flue gases;

4. Boiler surfaces coated with limestone;

All tests with the 3.2% S coal were conducted inadvertently with uncleaned furnace convection passes. An inoperative soot-blower valve was at fault, but could not be repaired until the 1.1% sulphur coal was bunkered.

These tests confirmed the effectiveness of the burner design changes and the model predictions for reducing carbon carryover. Subsequently, DND decided that no further hardware changes were necessary and requested that CCRL design a comprehensive series of acceptance tests to identify the conditions which optimize the operational reliability and flexibility of the burner and limestone injection systems.

ACCEPTANCE TESTS

The acceptance tests, which were divided into four phases in accordance with a format designed by the participants of the International Energy Agency Agreement on Low NO_x Coal Combustion, were conducted in February 1988. All tests, each of 1 1/2-2 1/2 h duration, were conducted using a 1.1% sulphur coal containing 2.3% ash; limestone was the only sorbent tested. Each phase of this test program is described below in the sequence performed.

Function Tests

Generator No. 2 was operated at full load and half load to ensure that all components of the burner and limestone systems were fully functional and calibrated for seasonal operation. Observations were made but no measurements were recorded during these tests.

Reference Tests

With all systems operating satisfactorily, reference tests were run at full load and half load without limestone injection, using the boiler settings established during the modified burner tests. These two tests provided an indication of the response times for controlling boiler load and burner performance and of the NO_x and SO_2 emissions against which a series of parametric tests could be compared. The results of the reference tests, designated as No. 1 and 14 in Table 11, closely agree with the modelling study which predicted that the carbon in ash would fall between 12 and 21% depending on char reactivity.

Table 11 - Acceptance test data

Test No.	Load MW	Swirl (1)	Tertiary Air (2)	O_2 % (3)	Injection Air Velocity	Oil MW	Ca/S	NO_x ppm(4)	SO_2 ppm(4)	Blr Effy %	Variable (5)
1	10	100	5	5.8	-	1	0	462	766	84.5	Ref
2	10	100	5	7.5	-	1	0	414	769	85.0	O_2
3	10	84	5	5.4	-	1	0	436	769	77.5	S
4	10	155	5	5.5	-	1	0	456	702	80.5	S
5	10	100	60	5.4	-	1	0	411	728	77.0	TA
6	10	100	100	5.9	-	1	0	391	709	79.5	TA
7	10	84	100	5.5	-	1	0	337	785	79.5	TA/S
8	10	100	5	5.8	high	1	0	435	721	81.0	IA
9	10	100	5	5.8	-	0.5	0	426	710	81.0	Oil
10	17	100	100	5.3	low	0.5	2.3	391	555	82.5	TA
11	17	100	100	5.1	-	0.5	0	345	722	84.5	TA
12	17	100	100	5.6	low	0.5	3.2	398	528	84.5	TA/IA/L
13	17	100	100	5.4	low	0.5	3.6	396	498	80.0	TA/IA/L
14	17	100	5	4.9	-	0.5	0	427	732	82.5	Ref
15	10	100	100	5.5	low(6)	0.5	1.3	357	576	84.0	TA/IA/L
16	10	100	100	5.7	high	0.5	2.4	313	570	83.0	TA/IA/L
17	10	100	100	5.1	high	0.5	4.1	292	432	81.5	TA/IA/L
18	18.5	100	100	4.2	low	0.5	3.7	427	558	81.0	TA/IA/L
19*	18.9	100	100	4.1	low	0.5	2.5	402	571	81.6	Optimal

(1) 100 = moderate; 84 = high; 155 = low

(2) Panel setting, %

(3) Induced draft fan inlet; furnace levels about 1% lower

(4) Corrected to 3.0% O_2 in the flue gases

(5) TA = tertiary air; IA = injection air; L = limestone; S = swirl

(6) Low injection velocities gave inconsistent feed rates

(*) 48h continuous test with limestone injection

Parametric Tests

A systematic series of 18 tests of 1 1/2 - 2 1/2 h duration were conducted at full load and half load to identify key operational parameters and to evaluate their influence on burner performance and emissions. The variables included secondary air swirl, tertiary air flow, injection air velocity, excess combustion air and calcium/sulphur ratio. Owing to the large decrease in primary airflow relative to the design specifications, the primary airflow setting was limited to within a damper setting of 22-26. Settings outside this range caused flame stability to deteriorate.

Although intended as a variable, the injection airflow rate had to be held constant because the injector required a minimum airflow rate to meter limestone consistently. This restriction resulted in the injection velocity at half load being twice that at full load. Table 11 gives the average results of duplicated parametric tests.

Performance Tests

A study of the parametric test results indicated that optimal conditions for a continuous 48 h performance test at full load with limestone injection would be provided by the following conditions:

a) Swirl setting 100
b) Tertiary air setting 100
c) O_2, % 3-4
d) Oil support, MW 0.5
e) Ca/S, mol/mol 2.5
f) Injection air velocity ..... Low

As shown in Table 11, under Test No. 19, these settings resulted

in reliable burner operations and acceptable boiler performance throughout the test. NO_x emissions relative to uncontrolled conditions were reduced by about 43% whereas sulphur capture with the 1.2% sulphur coal was about 22%. The boiler efficiency averaged 81.6%.

SUMMARY OF RESULTS

The normalized results of the demonstration program are highlighted in Figures 21 and 22. Figure 21 shows the trade-off between reductions in NO_x and increases in carbon carryover, and Figure 22 shows the influence of fuel sulphur content, the Ca/S mol ratio and the limestone addition method on sulphur capture. Relative to the baseline data from the original burners, the optimized settings for the staged burners provide a marked reduction in both NO_x and SO_2 without impacting on boiler efficiency. Figure 22 also shows that higher sulphur capture resulted from limestone injection in the tertiary air stream than from the addition of limestone to the coal feed.

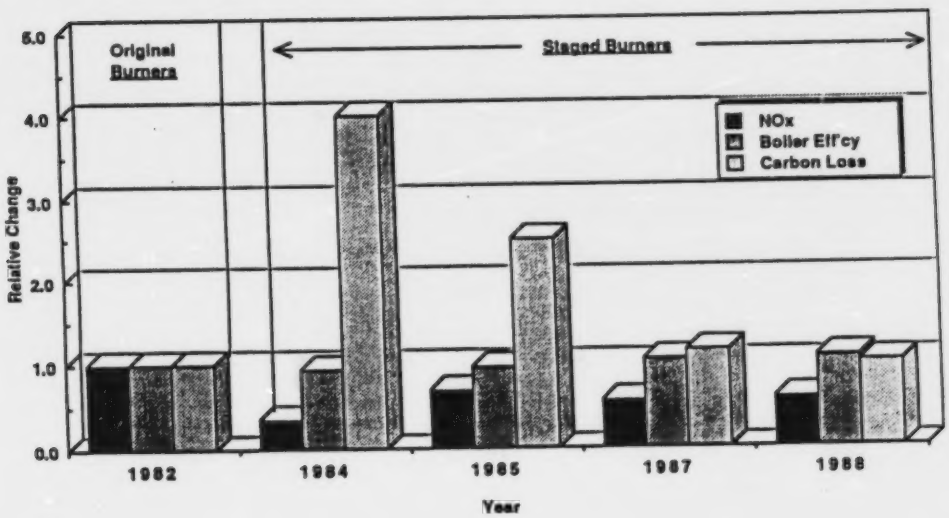


Fig. 21 - Change in NO_x, boiler efficiency and carbon loss relative to 1982 baseline levels

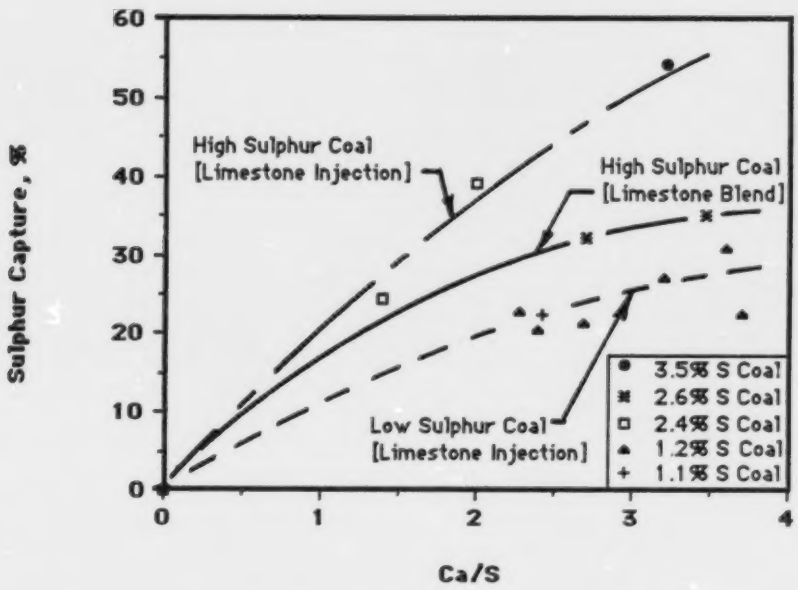


Fig. 22 - Influence of coal sulphur content, Ca/S ratio and limestone addition method on sulphur capture

CONCLUSIONS

1. The low NO_x/SO_x burner system, upon modification and optimization, was successful in reducing acid gas emissions by about 50% over baseline conditions.

2. The redesigned burner tip in conjunction with a 50% reduction in primary airflow eliminated flame pulsations, allowed the induced draft fan to generate a furnace draft and provided reliable ignition of the coal.

3. Sight ports in the furnace roof and walls facilitated use of the swirl adjustment to control flame shape and thus prevent impingement on furnace walls.

4. The settings selected for the 48 h performance test produced an acceptable trade-off between NO_x emissions and carbon carryover.

5. Limestone injection did not cause ash fouling of fireside surfaces. The deposits, which were soft and powdery, were readily removed by soot blowing.

6. The additive system transported, metered and injected limestone on demand. Once calibrated, its mass flow was predictable and consistent.

7. The use of limestone injection increases the ash loadings by 30 to 100% depending on the sulphur content of the coal being burned and the Ca/S ratio employed.

8. The burner management system reliably tripped the fuel supply well before the advent of marginal flame conditions and safely initiated burner startup in accordance with the management program.

9. The low NO_x/SO_x burner system has satisfied all of the operational conditions required by the Central Heating Plant at CFB Gagetown and the operating staff are knowledgeable and trained in all aspects of the technology.

ACKNOWLEDGEMENTS

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